

ANALOG
DEVICES



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DESCRIPTION

Based on considerable production experience, performance of the now familiar Model 180 operational amplifier series has been improved, and simultaneously, cost has been reduced. Drift of only $0.5\mu\text{V}/^\circ\text{C}$ makes the Model 180 the highest performance differential input chopperless op amp currently available. While chopper stabilized types still offer the ultimate in voltage drift performance, certain limitations are inherent in their application.

Specifically, since chopper stabilized amplifiers are nearly always single ended devices, they are limited to inverting applications. Since many applications require access to the non-inverting input, (high impedance followers, differential bridge circuits, etc) the 180 is of wide interest. Furthermore, it has additional advantages in smaller size, less weight, and lower cost than most chopper types. "Flicker" noise, common to choppers, is lower in the 180 and chopper "spikes" are, of course, totally absent.

WHERE TO USE THE 180

Because no single operational amplifier can solve all problems simultaneously, certain compromises must be made as "trade-offs" for superior performance in other key parameters. In this regard it will be found that the 180 is not the best amplifier for use in applications requiring high speed (i.e. wide bandwidth, high slew rates, fast settling time, etc). Additionally, where extremely high source resistances (above, say, $100\text{k}\Omega$) require the consideration of very low bias currents the 180 should not be considered the best choice. Analog Devices manufactures a wide variety of extremely fast amplifiers and has a very complete collection of FET and varactor bridge types for these specialized applications.

The 180 series is the best choice where very small signal levels (less than 1mV), from moderate source impedances (below $100\text{k}\Omega$), with modest frequency requirements (DC-5kHz) must be observed, measured or manipulated. Also in this group are larger signal levels that must be operated upon with a very high degree of accuracy, e.g. 1 volt to .01% accuracy. Low voltage drift and noise specifications are the prime requisites for proper solution to this class of op-amp application problems. Another application is the low drift/high input impedance buffer amplifier.

MODEL 180A/B/J/K CHOPPERLESS DIFFERENTIAL OPERATIONAL AMPLIFIER

FEATURES

Voltage Drift - $0.5\mu\text{V}/^\circ\text{C}$ max
Long Term Drift - $5\mu\text{V}/\text{month}$
Initial Offset Voltage - $100\mu\text{V}$
Warm-up Drift - $5\mu\text{V}$
Common Mode Rejection - 100,000
Bias Current Drift - $0.05\text{nA}/^\circ\text{C}$
Price - \$75. to \$110.



APPLICATIONS

High Impedance Buffer
Bridge Amplifier
Stable Voltage Source
Low Level Amplifier

ANALOG



DEVICES

221 FIFTH STREET
CAMBRIDGE, MASS. 02142
TEL: 617/492-6000
TWX: 710/320-0326

CHOPPERLESS DIFFERENTIAL OPERATIONAL AMPLIFIER

SPECIFICATIONS (typical @ 25°C unless otherwise noted)

MODEL	180A	180B	180J	180K
OPEN LOOP GAIN, rated load,min	300,000			
RATED OUTPUT				
Voltage, min	±10V			
Current, min	±2.5mA			
Load capacitance range	1000pf			
FREQUENCY RESPONSE				
Unity gain, small signal	1.0MHz			
Full power response, min	10kHz			
Slewing rate, min	0.6V/μs			
Overload recovery	2ms			
INPUT OFFSET VOLTAGE				
Initial offset 25°C, max*	±1mV**	±100μV	±250μV	±100μV
Avg. vs. temp(10 to 60°C)	—	—	±1.5μV/°C	±0.5μV/°C
vs. temp(-25 to 25 to 85°C)	±1.5μV/°C	±0.5μV/°C	—	—
vs. supply voltage	±2μV/%			
vs. time	±5μV/month			
Warm up drift (5 min)	5μV			
INPUT BIAS CURRENT				
Initial bias, 25°C,max	±4nA			
Avg. vs. temp(10 to 60°C)max	—	—	±0.1nA/°C	±0.05nA/°C
vs. temp(-25 to 85°C)max	±0.2nA/°C	±0.2nA/°C	—	—
vs. supply voltage	±0.2nA/%			
INPUT DIFFERENCE CURRENT				
Initial difference, 25°C	±1nA			
Avg. vs. temp(10 to 60°C)	—	—	±0.02nA/°C	±0.02nA/°C
Avg. vs. temp(-25 to 85°C)	±0.05nA/°C	±0.05nA/°C	—	—
INPUT IMPEDANCE				
Differential	2MΩ			
Common mode	1,000MΩ			
INPUT NOISE				
Voltage, .01 to 1Hz, p-p	1μV			
.01 to 100Hz, p-p	2μV			
5Hz to 50kHz, rms	4μV			
Current, .01 to 1Hz, p-p	50pA			
.01 to 100Hz,p-p	100pA			
INPUT VOLTAGE RANGE				
Common mode voltage, min	±10V			
Common mode rejection @ ±10V	100,000			
Max. safe differential voltage	±15V			
POWER SUPPLY				
Voltage, rated specification	±(15 to 16V)			
Voltage, derated specification	±(10 to 18V)			
Quiescent current, max	6mA			
Quiescent current	5.5mA			
TEMPERATURE RANGE				
Operating, rated specification	-25 to +85°C	-25 to +85°C	10 to 60°C	10 to 60°C
Operating, derated specifications	-55 to +85°C			
Storage	-55 to +85°C			
MECHANICAL				
Case Style - Pin Configuration	Q1			
Mating Socket	AC1003			
Weight	.85oz.			
PRICE				
1-9	\$80.	\$110.	\$75.	\$95.
10-24	\$76.	\$104.	\$72.	\$90.

*External resistor supplied.

**±250μV max; add \$5. and specify 180A0

Specifications subject to change without notice.

INITIAL OFFSET VOLTAGE

Most differential operational amplifiers have provisions for adjusting initial offset to zero with an external trim pot. It is not usually realized that there is a second order increase in voltage drift which accompanies the initial offset adjustment. The increased voltage drift due to balancing the amplifier can be safely ignored in conventional amplifiers since it is a small percentage of the specified voltage drift. But the voltage drift of the Model 180 is so small that this effect cannot be ignored. For example if a 100k pot were used to balance the initial offset voltage of the 180A (1mV initial offset), voltage drift could change by as much as $\pm 3\mu\text{V}/^\circ\text{C}$ and thus would exceed the specification.

The voltage drift of the Model 180 is measured and guaranteed when using a selected trim resistor. This resistor is supplied with the amplifier and the value for this resistor is inscribed on the unit. The specified voltage drift holds only when this value of resistance is externally connected between the amplifier's TRIM terminal and +15V. In this case initial offset voltage is guaranteed to be less than the specified value at $+25^\circ\text{C}$. Models 180B and K guarantee initial offset voltage to be less than $\pm 100\mu\text{V}$ ($\pm 250\mu\text{V}$ for 180J). In this case, an external 100k trim pot used to zero initial offset will not degrade voltage drift by more than ± 0.3 and $0.75\mu\text{V}/^\circ\text{C}$ respectively. The 180 can also be supplied on special order with the trim resistor connected internally.

INITIAL OFFSET ADJUSTMENTS

In some applications it may be desirable to zero the initial offset of the amplifier and an external bias network is recommended which will accomplish this purpose and allow the 180 to obtain lowest voltage drift. For the inverting configuration in Figure 1, the amplifier can be easily zeroed by summing an additional bias voltage (e_b) which is set equal to the initial offset of the amplifier.

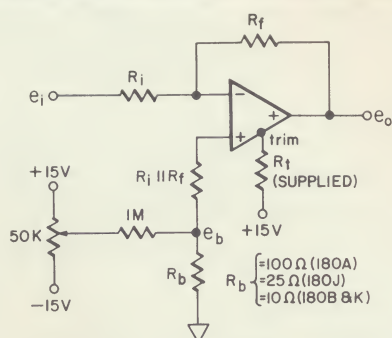


FIG. 1 BIASING CIRCUIT FOR INVERTING CONFIGURATION

The stability of the components or the $\pm 15\text{V}$ bias voltages is only moderately critical. For example: a 1% change of components or supply voltages would cause only about a $1.5\mu\text{V}$ change of offset voltage (where R_b equals ten ohms) and likewise a 0.1% control of these values will maintain a $.15\mu\text{V}$ offset. These figures should be multiplied by a factor of 2.5 and 10 for $R_b = 25$ and 100Ω respectively.

This circuit will also zero the offset due to initial difference current for values of R_i up to about 100k ohms. For larger values of R_i the value of R_b may have to be increased. Figure 2 shows a biasing circuit which can be used for the noninverting configuration.

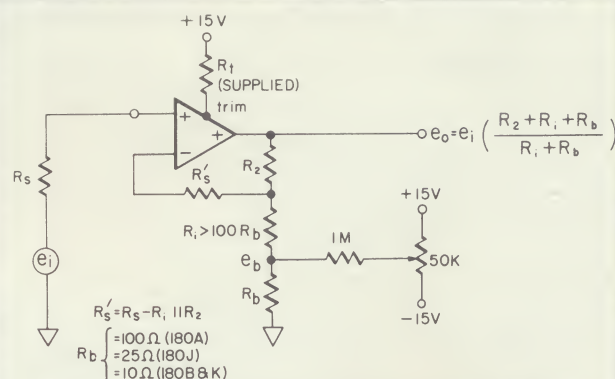


FIG. 2 BIASING CIRCUIT FOR NON-INVERTING CONFIGURATION

A large value for R_i as compared to R_b is only necessary for low closed loop gains (less than 10) to prevent the bias voltage, e_b , from changing as a function of the input voltage. For gains greater than 10, the minimum value for R_i can be reduced proportional to gain.

Of course, the circuit in Figure 2 will not work for unity gain. For this case a 100k ohm pot may be substituted for R_t to zero the amplifier. But it must be realized that the voltage drift will be increased by as much as $3\mu\text{V}/^\circ\text{C}$ for the 180A under the worst conditions. Alternatively, it is recommended that the Model 180B, J, or K be ordered with lower initial offset voltage ($\pm 100\mu\text{V}$, B or K, $\pm 250\mu\text{V}$, J) in which case the degradation due to zeroing with R_t will be one fourth to one tenth less. A similar circuit to Figure 2 can be used to bias the differential configuration of Figure 3.

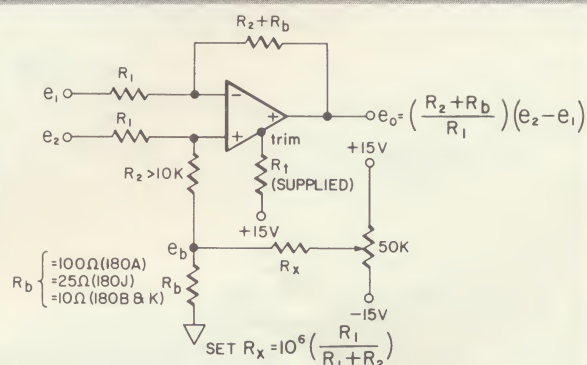


FIG. 3 BIASING CIRCUIT FOR DIFFERENTIAL CONFIGURATION

For very large gains (R_2/R_i) it may be necessary to use a larger value of R_b in the bias circuit in order not to load the bias voltage supplies.

TEMPERATURE GRADIENTS

Most differential operational amplifiers are critically sensitive to thermal gradients. The dual input transistor used in the Model 180 together with careful design and layout greatly reduces the unit's sensitivity to thermal gradients. The graph in Figure 4 shows the transient offset voltage (referred to the input) resulting from a thermal shock when the amplifier's temperature is abruptly changed from 25°C to 50°C by dipping it into a hot silicon oil bath. This very severe test is rarely encountered in practice but it does illustrate the amplifier's performance under worst conditions.

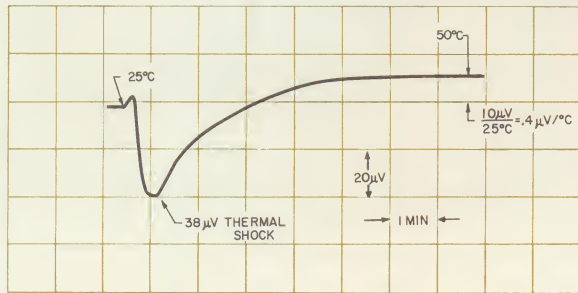


FIG. 4 TRANSIENT OFFSET VOLTAGE RESPONSE TO THERMAL SHOCK

WARM-UP DRIFT

The amplifier has exceptionally low warm up drift following the application of power supply voltage. Initial warm up drift is typically less than 5 μV over a period of 5 to 10 minutes.

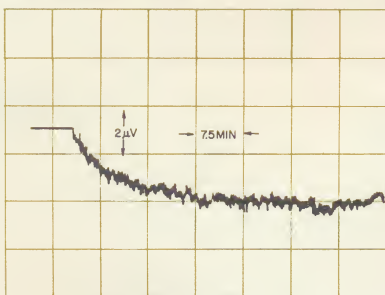


FIG. 5 TYPICAL WARM-UP DRIFT

LOW NOISE

Voltage noise of the 180 is extremely low for a transistor input amplifier. Low frequency or "flicker" noise is less than 1 μV p-p, over a bandwidth of .01 Hz to 1 Hz. This is contrasted with 5-20 μV p-p for chopper types. Additionally chopper amplifiers often exhibit high peak to peak values of chopper noise at and around the chopper frequency. This "spike" noise is, of course, absent in the chopperless 180. The accompanying graphs represent actual data taken on the 180 showing .01 Hz to 1 Hz noise, total voltage and current noise as a function of input resistance, (Fig. 6) and a plot of voltage and current noise per root cycle of bandwidth (Fig. 7).

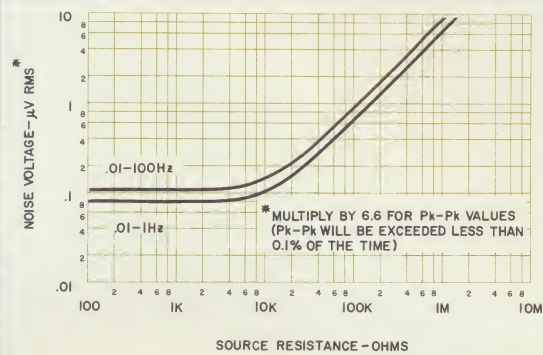


FIG. 6 EQUIVALENT VOLTAGE NOISE AS A FUNCTION OF INPUT RESISTANCE FOR CONSTANT BANDWIDTH

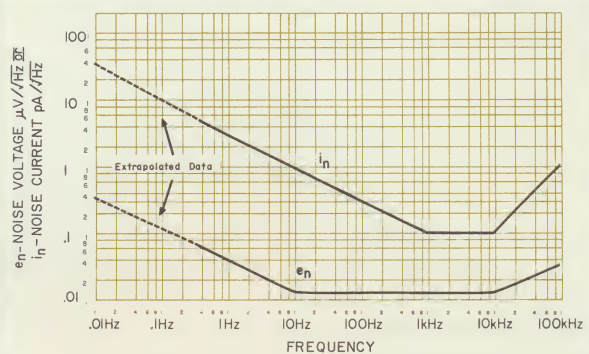


FIG. 7 VOLTAGE AND CURRENT NOISE PER ROOT CYCLE BANDWIDTH

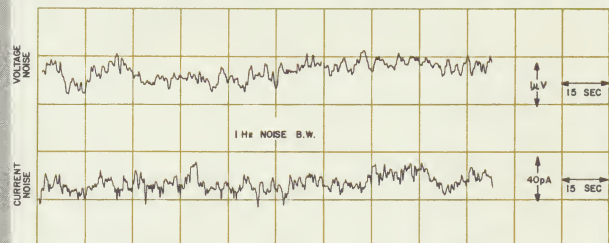


FIG. 8 TYPICAL VOLTAGE AND CURRENT NOISE .01 Hz to 1 Hz

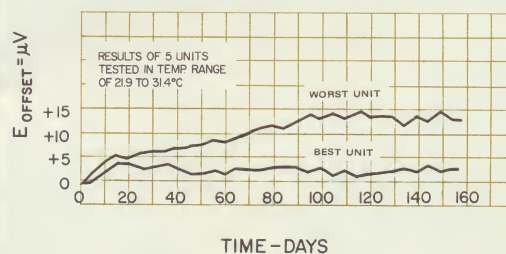


FIG. 9 LONG TERM STABILITY

CHOPPERLESS DIFFERENTIAL AMPLIFIERS

Until the advent of the new generation chopperless-differential op amps (pioneered by the Analog Devices Model 180), design engineers had been forced to either compromise their requirements and use existing differential amplifiers or apply the more costly chopper stabilized types, not without encountering certain other difficulties. The 180 is contrasted with these alternative approaches below.

VERSUS CHOPPER TYPES

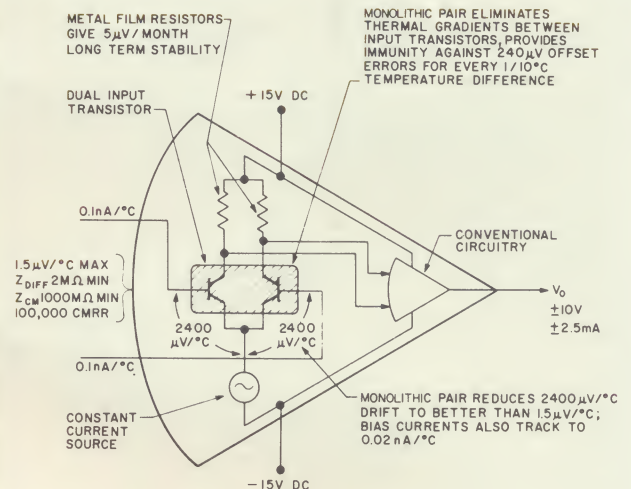
HIGH INPUT IMPEDANCE—Chopper amplifiers, while exceptionally good for low voltage drift, are generally single-ended input devices, and are only applicable as inverting amplifiers. The chopperless 180 provides the flexibility of true differential inputs and hence may be connected in the noninverting configuration. This connection "bootstraps" input impedance to $1000M\Omega$ (the common mode impedance). Most chopper amplifiers can achieve input impedances of only a few megohms. The 180 can also be connected in all other op-amp configurations requiring differential inputs.

LOW NOISE—The 180 is specified at $1\mu V$ p-p noise level in a bandwidth of .01Hz to 1Hz, an order of magnitude less than the "flicker noise" of most chopper types. Additionally, chopper amplifiers have high level "spikes" at the chopping frequency which are, of course, totally absent in the chopperless 180.

VERSUS CONVENTIONAL DIFF AMPS

THERMAL GRADIENTS—The superior drift and noise performance of the 180 is based on the use of special dual monolithic input transistors and proprietary thermal design techniques. One of the major limitations of previously available differential amplifiers has been their acute sensitivity to drift and noise errors introduced by thermal gradients. This means that while these amplifiers might be specified with $5\mu V/^{\circ}C$ drift coefficients, it is implied in this specification that the amplifier is subjected to a totally isothermal environment. In practice, however, this is rarely the case. Installation of the amplifier near cooling fans, transformers, power transistors, or other active devices will almost always produce a temperature difference between opposite sides of the amplifier and therefore, a thermal gradient across it. Since differential amplifiers depend on cancellation of V_{BE} voltages for their drift performance, this results in offset errors (and low frequency noise) far in excess of the published specifications and the designer's expectations. The aforementioned attention to special monolithic transistors and thermal design reduce this effect in the 180 by at least an order of magnitude.

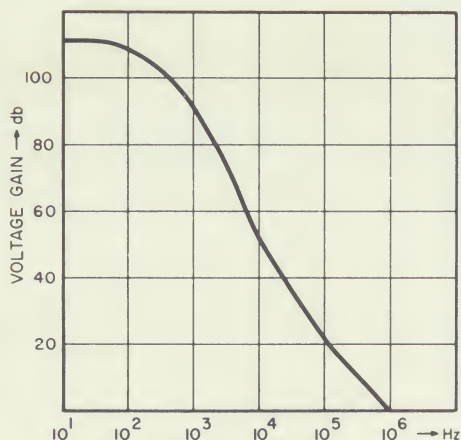
LONG TERM AND WARM-UP DRIFT—Special high stability metal film resistors are used at critical points in the design of the 180. Since resistor aging is the major cause of long term drift in operational amplifiers, the 180 specification of $20\mu V/\text{year}$ is several times better than amplifiers designed with carbon composition resistors (most low-cost op amps). Further, the combination of special components and thermal design limit warm-up drift to less than $5\mu V$, two orders of magnitude less than is found in most conventional differential op amps.



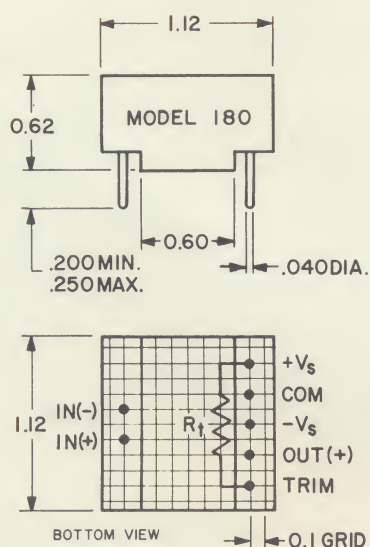
HOW THE MODEL 180 WORKS

The advanced performance of the Model 180 is based on a proprietary technique for closely matching the dual input transistors together with refined circuit design which minimizes every possible source of drift. Since the voltage offset of differential amplifiers depends on cancellation of the $2,400\mu V/^{\circ}C$ drift of each input transistor, a very small temperature difference between the junctions of the input pair caused by thermal gradients can cause a significant offset error. In the 180, the use of a monolithic pair at the amplifier input greatly reduces this source of error. As an illustration, an abrupt temperature shock from 25 to $50^{\circ}C$ generates a transient offset voltage of less than $100\mu V$, which is an order-of-magnitude improvement over conventional differential amplifiers.

OPEN LOOP RESPONSE



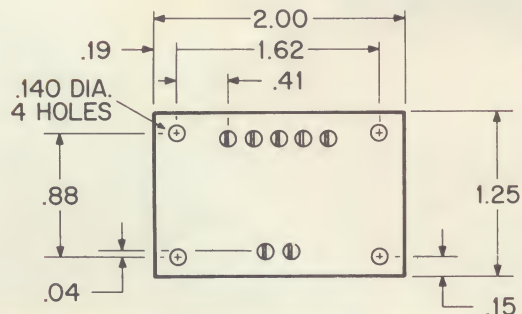
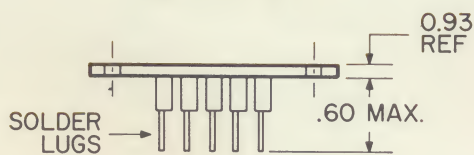
OUTLINE DIMENSIONS



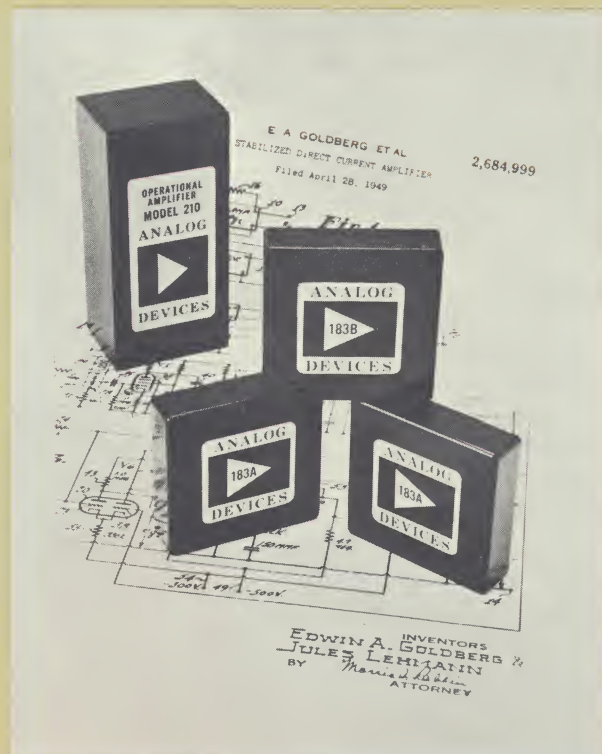
MATING SOCKET

AC1003

Price (1-9) \$2.75



OTHER LOW DRIFT AMPLIFIERS



A number of additional low drift amplifiers are available from Analog Devices. Among these is a complete line of chopper stabilized types including Models 230 ($0.1\mu\text{V}/^\circ\text{C}$, $0.5\text{pA}/^\circ\text{C}$, \$139 unit quantities) and Model 210 ($0.5\mu\text{V}/^\circ\text{C}$, $1.0\text{pA}/^\circ\text{C}$, \$157).

For high impedance applications where ultra low bias current is required, Models 141, 142, 143, 147 and 501 feature FET inputs. Models 301, 302, 310 and 311 are varactor bridge types with femto-amp bias currents.

The Model 183 is a chopperless differential amplifier similar to the 180 series with somewhat relaxed specifications and reduced cost.



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DESCRIPTION

The new Model 801 marks Analog Devices' entry into the monolithic I.C. op-amp field. The significance of this product is that bias current, difference current and current drift rates are improved by two orders of magnitude over currently available models. Bias current for the Model 801 is 4nA(max) as compared to 500nA for 709 types. Second generation 709's like the LM101, MC1539 and $\mu A741$ were aimed primarily at improving such features as short circuit protection, latch up, common mode voltage range, slewing rate and simplified compensation networks. However, as reflected in the comparative chart below, bias current, a major limitation in circuit applications, has been largely ignored. Thus linear I.C.'s have been excluded from many applications such as high impedance circuits, integrators, log amplifiers, and low level current amplifiers where bias current is the major contributor to circuit error. The Model 801 circuit is identical to the 709 except for the addition of a Darlington input stage, and thus it is completely interchangeable with the 709.

	UNITS	801A	801B	709*	741*	LM101*	MC1539*
Bias Current, 25°C	nA	4	4	500	500	500	500
Over temp. range	nA	11	11	1500	1500	1500	700
Difference Current, 25°C	nA	2	1	200	200	200	60
Over temp. range	nA	8	2	500	500	500	75
Offset Voltage, 25°C	mV	5	5	5	5	5	3
Over temp. range	mV	7.4	5.6	6	6	6	4
Open Loop Gain	V/V	15K	15K	25K	25K	25K	50K
Input Impedance	M Ω	25	25	0.15	0.3	0.3	0.15
Price (100 lot)	\$	9.75	13.00	6.60	7.00	8.80	7.50

*Published data July 1, 1968

TABLE 1. COMPARISON OF MAXIMUM SPECIFICATIONS FOR POPULAR IC TYPES

HIGH IMPEDANCE CIRCUITS

Figure 1 shows the effect of circuit impedance level on the offset error for operational amplifiers. For circuit impedance above 3k Ω , offset errors for existing I.C. types become severe, while the 801 can be used with impedance up to 300k Ω with comparable accuracy. This is a major breakthrough for linear I.C.'s which portends their use in an ever growing number of applications. Notice that difference current for the Model 801B does not exceed 20pA/°C, which challenges the performance of FET's.

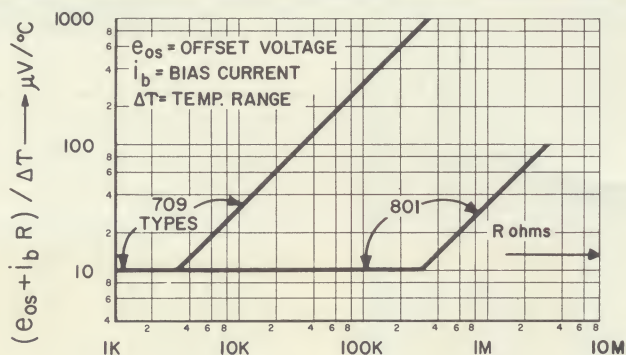


FIGURE 1. DRIFT ERROR VS. IMPEDANCE LEVELS

MODEL 801A/B/S

MONOLITHIC
INTEGRATED CIRCUIT
OPERATIONAL AMPLIFIER

FEATURES

Low Offset Current - 2nA max
Low Current Drift - 0.02nA/°C max
High Input Impedance - 25M Ω
Full Military Range - -55 to +125°C
Interchangeable with 709
Price (100 lots) \$9.75 to \$15.00



APPLICATIONS

High Impedance Circuits
Low Current Amplifier
Integrator
Sample/Hold Amplifier

ANALOG



DEVICES

221 FIFTH STREET
CAMBRIDGE, MASS. 02142
TEL: 617/492-6000
TWX: 710/320-0326

MODEL 801A/B/S

MONOLITHIC INTEGRATED CIRCUIT OPERATIONAL AMPLIFIER

SPECIFICATIONS (typical @ $T_a = 25^\circ\text{C}$ and $V_s = \pm 15\text{V}$ unless otherwise noted)

OPEN LOOP GAIN

$R_L \geq 2\text{k}\Omega$, $E_o = \pm 10\text{V}$, min 15,000

RATED OUTPUT VOLTAGE

$R_L \geq 2\text{k}\Omega$, min $\pm 10\text{V}$

TRANSIENT RESPONSE (see test circuit—page 3)

Rise time for $V_{in} = 20\text{mV}$, max $2\mu\text{sec}$
Overshoot, max 30%

INPUT OFFSET VOLTAGE

	Model A	Model B	Model S
@ 25°C , max	$\pm 5\text{mV}$	$\pm 5\text{mV}$	$\pm 5\text{mV}$
Over temprange (T_l to T_h), max	$\pm 7.4\text{mV}$	$\pm 5.6\text{mV}$	$\pm 7.0\text{mV}$
Avg. vs. temp (T_l to 25°C to T_h), max	$\pm 40\mu\text{V}/^\circ\text{C}$	$\pm 10\mu\text{V}/^\circ\text{C}$	$\pm 20\mu\text{V}/^\circ\text{C}$
vs. supply voltage, max	$\pm 200\mu\text{V}/\text{V}$	$\pm 200\mu\text{V}/\text{V}$	$\pm 200\mu\text{V}/\text{V}$

INPUT BIAS CURRENT

	Model A	Model B	Model S
@ 25°C , max	4nA	4nA	4nA
Over temprange (T_l to T_h), max	11nA	11nA	16nA
Avg. vs. temp (T_l to 25°C to T_h), max	$0.15\text{nA}/^\circ\text{C}$	$0.15\text{nA}/^\circ\text{C}$	$0.15\text{nA}/^\circ\text{C}$
vs. supply voltage, max	$0.02\text{nA}/\text{V}$	$0.02\text{nA}/\text{V}$	$0.02\text{nA}/\text{V}$

INPUT DIFFERENCE CURRENT

	Model A	Model B	Model S
@ 25°C , max	$\pm 2\text{nA}$	$\pm 1\text{nA}$	$\pm 2\text{nA}$
Over temprange (T_l to T_h), max	$\pm 8\text{nA}$	$\pm 2\text{nA}$	$\pm 5\text{nA}$
Avg. vs. temp (T_l to 25°C to T_h), max	$0.1\text{nA}/^\circ\text{C}$	$0.02\text{nA}/^\circ\text{C}$	$0.03\text{nA}/^\circ\text{C}$

INPUT IMPEDANCE

Differential, min $25\text{M}\Omega$
Common mode $500\text{M}\Omega$

INPUT VOLTAGE NOISE ¹

.01 to 10Hz, p-p $100\mu\text{V}$
10Hz to 5kHz, rms $6\mu\text{V}$

INPUT VOLTAGE RANGE

Common mode voltage, min $\pm 8\text{V}$
Common mode rejection, min 65dB
Max. safe differential voltage $\pm 10\text{V}$

POWER SUPPLY

Voltage, rated specification $\pm (15 \text{ to } 16)\text{V}$
Voltage, derated specification $\pm (5 \text{ to } 18)\text{V}$
Current, quiescent, max $\pm 6\text{mA}$

TEMPERATURE RANGE

	Model A	Model B	Model S
Operating, rated specifications	$T_l = -25^\circ\text{C}$ $T_h = +85^\circ\text{C}$	$T_l = -25^\circ\text{C}$ $T_h = +85^\circ\text{C}$	$T_l = -55^\circ\text{C}$ $T_h = +125^\circ\text{C}$
Operating, derated specifications	$-55 \text{ to } +125^\circ\text{C}$	$-55 \text{ to } +125^\circ\text{C}$	$-55 \text{ to } +125^\circ\text{C}$
Storage	$-65 \text{ to } +150^\circ\text{C}$	$-65 \text{ to } +150^\circ\text{C}$	$-65 \text{ to } +150^\circ\text{C}$

MECHANICAL

Case style - pin configuration TO99

PRICE

	Model A	Model B	Model S
1-24	\$14.	\$19.	\$23.
25-99	\$12.	\$16.	\$19.
100-999	\$ 9.75	\$13.	\$15.

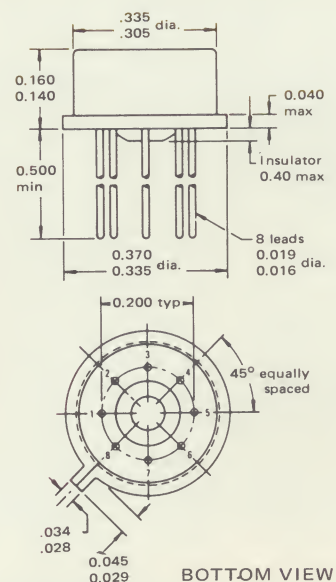
¹ $C_1 = 5000\text{pF}$, $R_1 = 1.5\text{k}\Omega$, $C_2 = 200\text{pF}$ as shown in Frequency Compensation Circuit. Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS

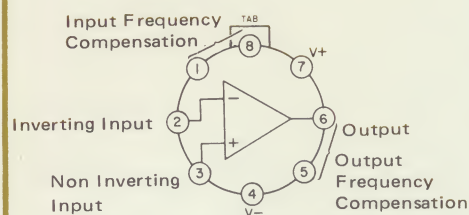
Supply Voltage	$\pm 18\text{V}$
Internal Power Dissipation ¹	300mW
Differential Input Voltage	$\pm 10\text{V}$
Input Voltage	$\pm 10\text{V}$
Storage Temp Range	$-65 \text{ to } 150^\circ\text{C}$
Operating Temp Range	$-55 \text{ to } 125^\circ\text{C}$
Lead Temp (soldering, 60sec)	300°C
Output Short-Circuit	
Duration ($T_a = 25^\circ\text{C}$)	5sec

¹ For case temperatures to 125°C ; derate linearly at $5.6\text{mW}/^\circ\text{C}$ for ambient temperatures above 95°C .

OUTLINE DIMENSIONS

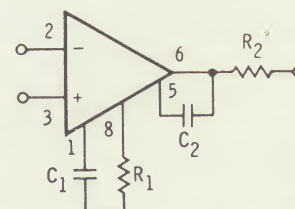


CONNECTION DIAGRAM



NOTE: Pin 4 connected to case.
TOP VIEW

FREQUENCY COMPENSATION CIRCUIT

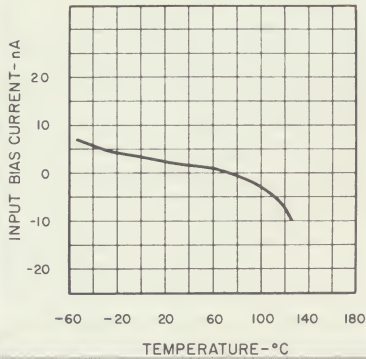


Use $R_2 = 50\Omega$ when the amplifier is operated with capacitive loading.

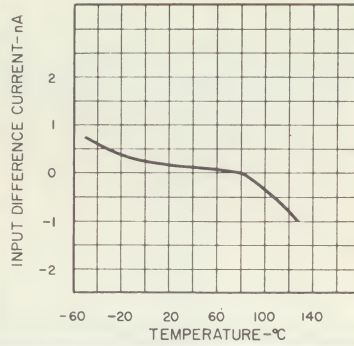
TYPICAL PERFORMANCE CURVES

(@ $\pm 15V$ unless otherwise specified)

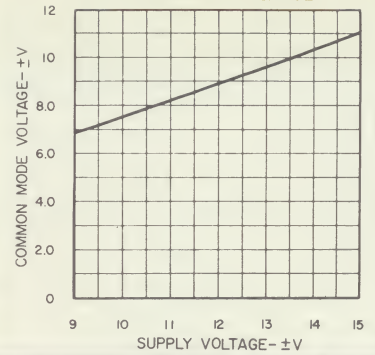
BIAS CURRENT VS. TEMPERATURE



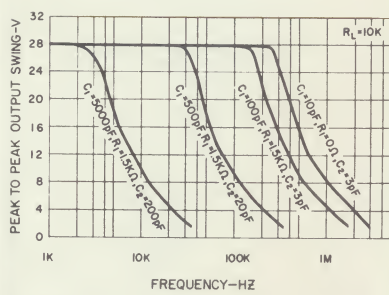
DIFFERENCE CURRENT VS. TEMPERATURE



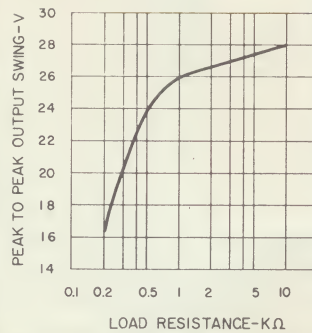
COMMON MODE VOLTAGE VS. SUPPLY VOLTAGE



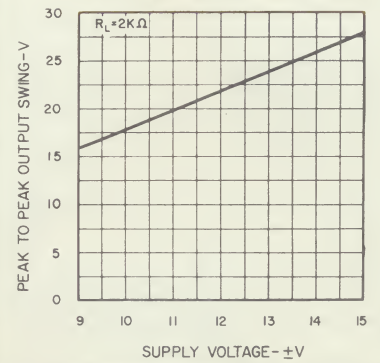
OUTPUT VOLTAGE VS. FREQUENCY



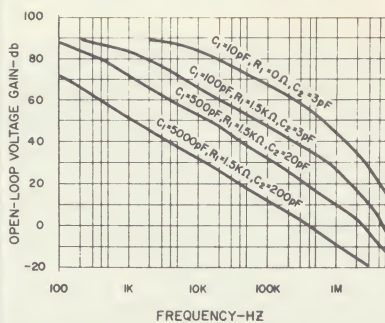
OUTPUT VOLTAGE VS. LOAD RESISTANCE



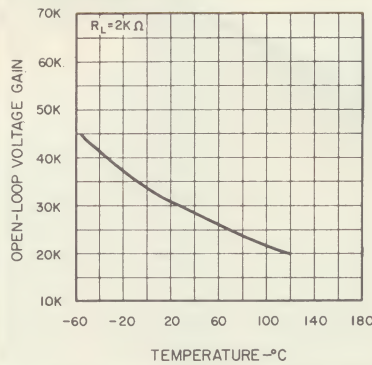
OUTPUT VOLTAGE VS. SUPPLY VOLTAGE



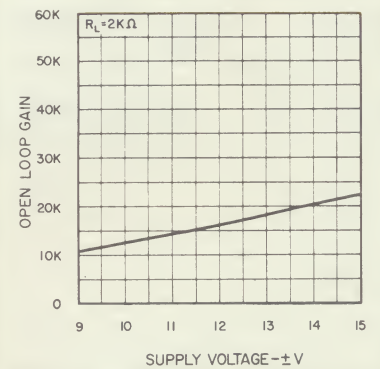
VOLTAGE GAIN VS. FREQUENCY



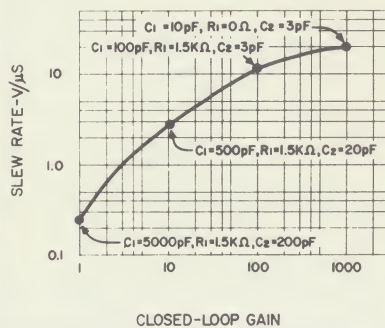
VOLTAGE GAIN VS. TEMPERATURE



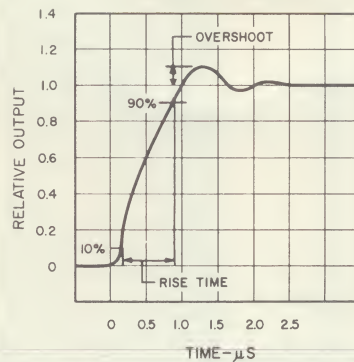
VOLTAGE GAIN VS. SUPPLY VOLTAGE



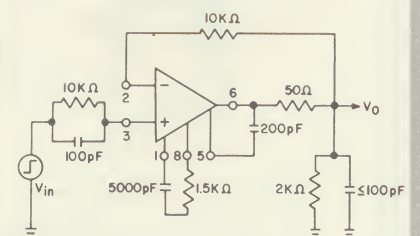
SLEW RATE VS. CLOSED LOOP GAIN



TRANSIENT RESPONSE



TRANSIENT RESPONSE TEST CIRCUIT



APPLICATION NOTES

Notice from the schematic diagram below that the Model 801 is identical to the 709 except that a Darlington stage has been added at the input to reduce bias current and that a few resistor values in the 709 circuit have been changed resulting in slightly lower open loop gain.

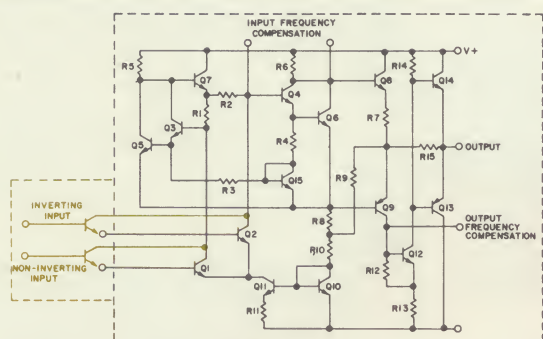


FIG. 2 SCHEMATIC DIAGRAM

On the one hand the Model 801 has the advantage of having characteristics with which 709 users are already familiar. On the other hand the 709 has a number of circuit limitations which must be corrected by the addition of external components. The Fairchild Linear Integrated Circuits Handbook (pages 57 to 72) includes a thorough discussion of the 709 circuit, and how to overcome its limitations. This discussion is for the most part applicable to the 801 as well but we shall repeat a few of the more notable operating precautions here for your convenience.

OUTPUT SHORT CIRCUIT PROTECTION

The Model 801 will withstand short circuits at 25°C for about 5 seconds. However, temperature rise due to internal dissipation will eventually damage the device and the time period is accelerated at higher ambient temperatures.

Protection against short circuits to ground of any duration can be obtained simply by inserting a small resistor, R_{17} , in series with the output to limit the maximum power dissipation. A 200 ohm resistor shown in Figure 3 will completely protect the 801 for short circuit at ambient temperatures up to 75°C or at case temperatures to 125°C. The only penalty paid for this resistor is about a 10% reduction in maximum output voltage swing into a 2k ohm load. Otherwise the effects of this resistor are reduced by being inside the feedback loop.

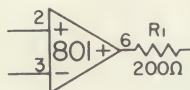


FIG. 3 OUTPUT SHORT CIRCUIT PROTECTION

LATCH UP

When used as a voltage follower or noninverting amplifier, the 801 may latch up when the input is overdriven by a transient or a signal overdrive. That is, when the inverting input saturates, it no longer inverts and therefore positive feedback from the output will hold the inverting input at saturation even after the input or transient overdrive is removed. This problem can usually be cured by adding a 33k ohm resistor in series with the inverting input to limit the amount of feedback current.

FREQUENCY COMPENSATION

The Model 801 will give about one half the gain-bandwidth product as the 709 when used with the same frequency compensation components. The charts on page three (referenced to Frequency Compensation Circuit on page 2) give some idea of the component values to use. However for a complete discussion of this subject see the Fairchild Linear Integrated Circuits Handbook (pages 65 to 68).

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Although the bias current of the 801 is already 100 times lower than other available I.C.'s, it is possible to even further reduce errors due to bias current by balancing the impedance at each input. This is illustrated by the circuit in Figure 4 where we insert a resistor R_C equal to the parallel sum of R_i and R_f . The more general rule is to balance impedance such that the impedance to ground seen looking out of the inverting and noninverting inputs is equal.

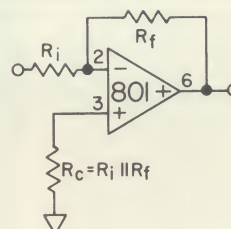


FIG. 4 BIAS CURRENT COMPENSATION

The benefit of balancing impedances is that now difference current rather than bias current is used to calculate circuit errors. For example, bias current drift for the 801B is 0.15nA/°C while difference current drift is only 0.02nA/°C, a five times improvement.

VERSUS FET'S

With 0.02nA/°C current drift, the performance of the Model 801 rivals that of FET's. In fact, since bias current of FET's doubles each 10°C, errors due to input current for the 801 will actually be less than that of FET's. This is especially true for the Model 801S where difference current does not exceed ± 5 nA at +125°C. In addition, FET's have higher voltage drift and poorer CMRR than the transistor input of the Model 801.

DESCRIPTION

The new Model 801 marks Analog Devices' entry into the monolithic I.C. op-amp field. The significance of this product is that bias current, difference current and current drift rates are improved by two orders of magnitude over currently available models. Bias current for the Model 801 is 4nA(max) as compared to 500nA for 709 types. Second generation 709's like the LM101, MC1539 and $\mu A741$ were aimed primarily at improving such features as short circuit protection, latch up, common mode voltage range, slewing rate and simplified compensation networks. However, as reflected in the comparative chart below, bias current, a major limitation in circuit applications, has been largely ignored. Thus linear I.C.'s have been excluded from many applications such as high impedance circuits, integrators, log amplifiers, and low level current amplifiers where bias current is the major contributor to circuit error. The Model 801 circuit is identical to the 709 except for the addition of a Darlington input stage, and thus it is completely interchangeable with the 709.

	UNITS	801A	801B	709*	741*	LM101*	MC1539*
Bias Current, 25°C	nA	4	4	500	500	500	500
Over temp. range	nA	11	11	1500	1500	1500	700
Difference Current, 25°C	nA	2	1	200	200	200	60
Over temp. range	nA	8	2	500	500	500	75
Offset Voltage, 25°C	mV	5	5	5	5	5	3
Over temp. range	mV	7.4	5.6	6	6	6	4
Open Loop Gain	V/V	15K	15K	25K	25K	25K	50K
Input Impedance	M Ω	25	25	0.15	0.3	0.3	0.15
Price (100 lot)	\$	9.75	13.00	6.60	7.00	8.80	7.50

*Published data July 1, 1968

TABLE 1. COMPARISON OF MAXIMUM SPECIFICATIONS FOR POPULAR IC TYPES

HIGH IMPEDANCE CIRCUITS

Figure 1 shows the effect of circuit impedance level on the offset error for operational amplifiers. For circuit impedance above 3k Ω , offset errors for existing I.C. types become severe, while the 801 can be used with impedance up to 300k Ω with comparable accuracy. This is a major breakthrough for linear I.C.'s which portends their use in an ever growing number of applications. Notice that difference current for the Model 801B does not exceed 20pA/°C, which challenges the performance of FET's.

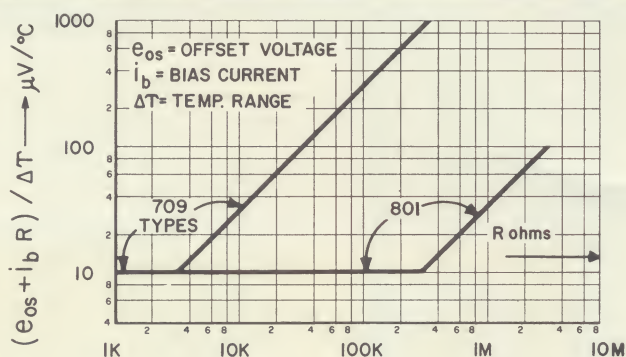


FIGURE 1. DRIFT ERROR VS. IMPEDANCE LEVELS

MODEL 801A/B/S

MONOLITHIC
INTEGRATED CIRCUIT
OPERATIONAL AMPLIFIER

FEATURES

Low Offset Current - 2nA max
Low Current Drift - 0.02nA/°C max
High Input Impedance - 25M Ω
Full Military Range - -55 to +125°C
Interchangeable with 709
Price (100 lots) \$9.75 to \$15.00



APPLICATIONS

High Impedance Circuits
Low Current Amplifier
Integrator
Sample/Hold Amplifier

ANALOG



DEVICES

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CAMBRIDGE, MASS. 02142
TEL: 617/492-6000
TWX: 710/320-0326

APPLICATION NOTES

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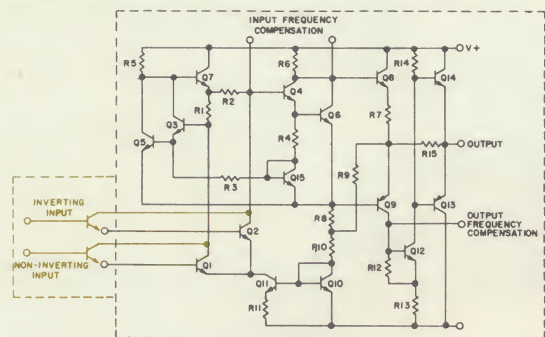


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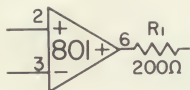


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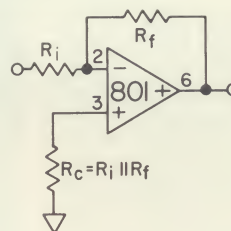


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LOGARITHMIC DEVICES — A MATTER OF NOMENCLATURE

In *communication* or *audio* parlance, a logarithmic or exponential amplifier is one in which the input and output wave shapes are identical, and the output level varies as the logarithm or a power of the input level, averaged over many cycles of the signal frequency. In *analog* technology, however, the output is proportional to the logarithm or a power of the *instantaneous* value of the input signal. The logarithm of zero being an indeterminate number, a zero input signal condition is ruled out and analog logarithmic devices are confined to a single quadrant.

DESCRIPTION

Model 751P/N Logarithmic Modules contain the nonlinear components needed to instrument a wide range of exponential, logarithmic and ratio measuring circuits in the "analog" sense of those words. The circuitry includes a pair of silicon transistors — NPN types in the Model 751N and PNP types in the Model 751P — and a temperature compensating voltage divider.

The transistors are chosen for their conformity to the ideal logarithmic current-to-voltage relationship; their characteristics are closely matched and they are thermally coupled to minimize temperature differences between their junctions. The voltage divider, used in the feedback network of an operational amplifier, is designed to boost the voltage difference between the two transistors to one volt per decade of current ratio through them, while simultaneously compensating for the temperature dependence of the matched transistor pair. Each module is adjusted and calibrated to assure compliance to the specifications given herein.

The Model 751P/N is normally used in conjunction with one or more operational amplifiers and thus the circuitry of the module is brought out on separate pins to allow maximum versatility of interconnection. The unit is molded into an epoxy filled module which can be soldered directly onto a printed circuit board or plugged into an optional mating socket.

THE GENDER — 751P or 751N

Transistors are one-way devices. The collector current of an NPN transistor must flow into the collector, while that of a PNP model flows out of the collector terminal. The arrows in the conventional transistor schematics point the way!

In selecting a 751 module for a trans-diode or transistor connection, establish the direction of the signal current flow and specify 751P or N accordingly. Photomultiplier and ion chamber currents generally require a -P model. Most other applications, including all diode connections, are better instrumented with a model 751-N, as these, typically come with a closer transistor match and thus give better accuracy. Note that a diode connected transistor is a two-terminal device which can be oriented to suit the direction of the signal current.

MODEL 751P/N

PRECISION LOGARITHMIC MODULE

FEATURES

Wide Dynamic Range, 10pA to 1mA

Calibrated 1V/Decade Output

Temperature Compensated to 0.05%/°C

Low Cost - \$20(100 quantity) - \$38(1-9)



APPLICATIONS

Current or Voltage Ratiometers

Logarithmic Compressors

Exponential Expanders

Arbitrary Powers and Roots

ANALOG



DEVICES

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TEL: 617/492-6000
TWX: 710/320-0326

PRINCIPLE OF OPERATION

If the base and collector of a forward biased transistor are held at the same voltage, its base-emitter voltage is proportional to the logarithm of the collector current. This basic property may be exploited by connecting the transistor in the feed-back network of an operational amplifier in one of the three basic configurations shown below. With each, the collector current range of close conformity to the ideal logarithmic function is marked.

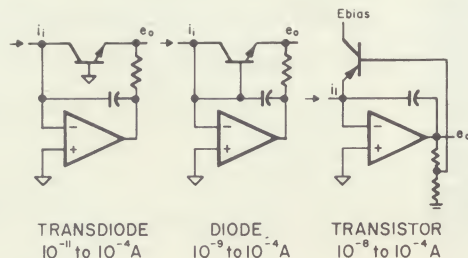


FIGURE 1. BASIC LOGARITHMIC CONFIGURATIONS

All three basic configurations are subject to intolerable temperature sensitivity and dynamic instability unless a few straight-forward circuit design precautions are taken. Model 751 contains the required set of matched temperature compensating components. For the theoretical know-how and a set of proven circuits, see "Analog Dialogue", Vol. II No. 2.

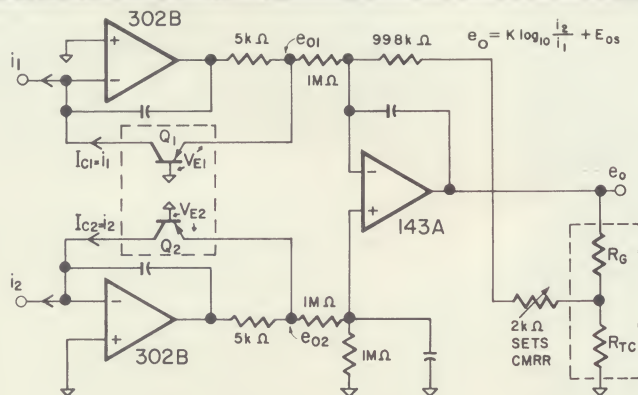
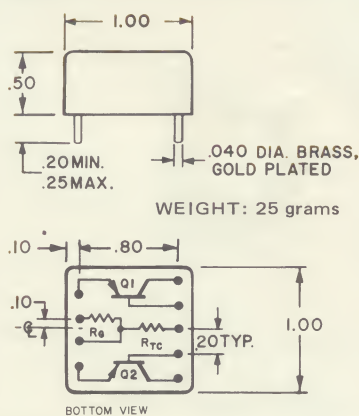
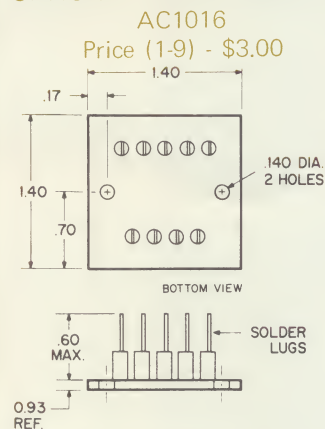


FIGURE 2. TEST CIRCUIT: LOG OF CURRENT RATIO

OUTLINE DIMENSIONS



OPTIONAL MATING SOCKET



SPECIFICATIONS

(Typical at 25°C unless stated differently.)
(For 751P and 751N, unless shown separately.)

TRANSISTORS

Maximum Ratings:	751P	751N
V_{EBO}	5V	4V
V_{CBO}	40V	40V
V_{CEO}	40V	25V
I_C	.05A	0.1A
P_D	0.5W	0.3W

Current Gain:

$$h_{fe1}, h_{fe2} \geq 100 @ I_C = 10\mu A$$

Transistor Match @ $V_{CB1} = V_{CB2} = 0$:

$$|V_{BE1} - V_{BE2}| < 0.5mV, 1nA < I_{C1} = I_{C2} < 0.1mA$$

RESISTORS:

$$R_{TC} = 955\Omega \pm 1\% @ 25^\circ C, +0.3\%/^\circ C$$

$$R_G = 15k\Omega \pm 2\%, \text{ selected}$$

PERFORMANCE IN TEST CIRCUIT (Fig. 2)

All amplifiers zeroed and not contributing errors

$$e_o = K \log_{10} \frac{i_2}{i_1} + E_{os} \quad (\text{definition})$$

$$\underbrace{K_{25} + \frac{\Delta K}{\Delta T} (T - 25^\circ C)}_{\text{Slope}} \quad \underbrace{E_{os25} + \frac{\Delta E_{os}}{\Delta T} (T - 25^\circ C)}_{\text{Offset}}$$

Composite Specifications:

(Typical unless stated otherwise.)

$$K_{25} = 1000 \pm 5 (\text{max}) \text{ mV/decade}, 1nA < i_1, i_2 < 0.1mA$$

$$\pm 15mV/\text{decade}, 100pA < i_1, i_2 < 1mA$$

$$\frac{\Delta K}{\Delta T} = \pm 0.45 (\text{max}) \text{ mV/decade}/^\circ C, 1nA < i_1, i_2 < 1mA$$

$$= \pm 0.45 \text{ mV/decade}/^\circ C, 100pA < i_1, i_2 < 1nA$$

$$E_{os25} = \pm 8 (\text{max}) \text{ mV}, 1nA < i_1, i_2 < 0.1mA$$

$$\pm 15mV (751P) \quad \left. \begin{array}{l} \pm 8mV (751N) \end{array} \right\} 100pA < i_1, i_2 < 1mA$$

$$\frac{\Delta E_{os}}{\Delta T} = \pm 0.1 (\text{max}) \text{ mV}/^\circ C, 1nA < i_1, i_2 < 1mA$$

$$\pm 0.25 \text{ mV}/^\circ C (751P) \quad \left. \begin{array}{l} \pm 0.15 \text{ mV}/^\circ C (751N) \end{array} \right\} 100pA < i_1, i_2 < 1nA$$

TEMPERATURE RATINGS:

Performance to above specifications:	10 to 60°C
Operating:	-25 to 85°C
Storage:	-55 to 100°C

PRICE

1-9	\$38.
10-24	\$30.

All specifications subject to change without notice



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TEL.: 617/492-6000
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☐ Chopper Stabilized	☐ Active Filters	☐	☐
☐ Low Drift Differential	☐ Power Supplies	☐	☐
☐ Integrated Circuit	☐ Log Modules	☐	☐
☐ Microcircuit Hybrid	☐ Instrumentation Amplifiers	☐	☐
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		My principal source of supply is: _____	

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